Screening for Childhood Lead Exposure Using a Geographic Information System and Internet Technology

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Abstract

Childhood exposure to lead remains a critical health issue to the United States population. The widespread distribution of lead throughout the environment and the profound physiological and cognitive effects it has on children, even at low levels, warrant an aggressive approach toward identifying lead hazards in the environment, determining the population at risk for lead exposure, and developing strategies to prevent exposure. In 1991, the Centers for Disease Control and Prevention (CDC) issued a recommendation supporting near-universal blood lead testing of children under the age of six years. This recommendation is currently under revision, having been criticized as ineffective and unnecessary. Recently, the CDC has issued an updated lead screening guidance document recommending the evaluation of individual and residential exposure risks in order to target screening efforts in areas where lead risks are significant. Dakota County (Minnesota) staff have developed a geographic information system application that spatially evaluates lead sources and returns a screening recommendation based on an individual's risk of exposure to lead. Health professionals can obtain an individual's exposure risk from an Internet Web site simply by entering a residential address. The Web site returns an overall risk value for the specific location by incorporating these lead risk elements. The use of a standard Web browser allows for the cost-effective delivery of accurate and current information. The Internet server also allows the data and application to be updated as needed at a central location without the need to redistribute the data.

Keywords: targeted-screening, lead poisoning, environmental lead

Introduction

Childhood exposure to lead remains a critical health issue confronting the United States population. Although this exposure, as measured by blood lead levels, has fallen dramatically since the 1970s (1,2), significant numbers of children continue to be exposed to toxic levels of lead. Overexposure to lead, however, is not equally distributed in all segments of the population. A 1988 report by staff of the Agency for Toxic Substances and Disease Registry (ATSDR) found that childhood blood lead levels were significantly associated with race, family income, residence inside or outside a metropolitan central city, and, for city residents, the size of the metropolitan area (3). These findings are supported by the results of the recent National Health and Nutrition Examination Surveys (NHANES), which found elevated blood lead levels disproportionately distributed among children who are "poor, non-Hispanic black or Mexican American, living in large metropolitan areas, or living in older housing" (4).

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Within the past two decades, research on childhood lead poisoning has identified profound, adverse physiological and cognitive affects from low-level exposure (5–11). The neurotoxicity of lead is of considerable concern. Several prospective studies have identified significant dose-dependent relationships between lead exposure and impaired neurobehavioral and psychological functioning (12–15). Followup studies of adults with asymptomatic exposure to lead as children have demonstrated that children with early elevated lead exposure were at risk for later educational deficiencies including failure to graduate and poorer reading abilities (16,17). The findings of these and other studies suggest that the deleterious effects of early childhood exposure to low levels of lead result in profound and long-lasting impacts on learning and behavior.

In response to these data, in 1991, the Centers for Disease Control and Prevention (CDC) issued revised guidelines for management of lead poisoning. These new guidelines significantly lowered the levels at which children are considered at risk for lead toxicity (18). The guidelines led to a recommendation to screen virtually all children between the ages of 12 months and 72 months. The CDC also recommended that physicians administer a five-part questionnaire in order to classify children as being at high risk or low risk for lead exposure.

The CDC's recommendation of near-universal lead toxicity screening for children under six has proven to be very controversial. Critics of universal screening have challenged the necessity of the recommendation, citing the dramatic reduction of blood lead levels in the nation's preschool children since 1976. Two additional reasons frequently cited are the low prevalence of elevated blood lead levels in much of the population and the high costs of universal screening (19).

Because of these criticisms, the CDC's recommendation has not been followed by many primary health care providers. Relatively few children in any region of the country have been screened for lead exposure. In a nationwide survey conducted by the CDC in 1994, only about one-fourth of parents reported that their young children had been screened (20). In addition, a survey of New Jersey pediatricians and family practitioners found that only 42% of pediatricians and 24% of family practitioners reported screening the majority of children seen in their practice by the age of two (21).

To address these issues and to further improve the use of screening to identify and prevent childhood lead poisoning, the CDC issued an updated lead screening guidance document in November 1997, entitled Screening Young Children for Lead Poisoning: Guidance for State and Local Public Health Officials (20). The guidance document refers to the use of census tract data, personal risk questionnaires, the socioeconomic status of patients, and other data, to identify and deliver proper services to children at greatest risk for lead exposure.

Dakota County (Minnesota) staff have developed a geographic information system (GIS) application to assist in the identification of populations at high risk for exposure to lead hazards. The application combines information representing risk factors for lead exposure, including the age and distribution of housing, location of lead-emitting sources, distribution of lead-contaminated soils, case mapping of lead poisoning, and demographic data. An individual's overall lead exposure risk can be modeled and classified by incorporating the various contributors to lead overexposure as they relate to the individual's home address. The application is accessed using a standard Web browser, allowing for cost-effective delivery of accurate and current information. Dakota County is in the process of applying for funding from the Minnesota

Department of Health through a grant from the State and Community-Based Childhood Lead Poisoning Prevention Program, which is administered by the CDC. If received, the funding will be used to assess the usefulness of the model and to evaluate the risk factors employed in the model.

Setting

Dakota County is located in Minnesota, on the south side of the Minneapolis/St. Paul seven-county metropolitan area. The county was originally settled in the mid-1850s. Its 1997 population is estimated at 330,000. It is the second-fastest-growing county in the 87-county state, and its population is younger than the statewide and metropolitan averages. Though Dakota County was once largely rural, the second half of this century has seen the intensive suburbanization of the county's northern half. The county is home to 40 regulated solid waste facilities, including two of the state's largest sanitary landfills. The county also licenses and inspects nearly 1,300 hazardous waste generators and facilities, including a large secondary lead smelter. The housing stock is considerably newer than that of the Twin Cities, with approximately 10% of the homes constructed prior to 1950. However, concentrations of older housing are found in cities developed when streetcars were the primary mode of transportation, as well as in communities that historically served as agricultural centers.

Overview of the Lead Exposure Risk Assessment Application

The GIS application, developed in Dakota County, is intended as a tool to help determine when blood lead testing is necessary. The application does not, however, account for all the potential risks that contribute to lead poisoning, and health care providers must still make their own assessments to determine whether or not to perform blood lead testing.

The GIS application was developed in Microsoft Visual Basic and is accessed using a standard Web browser through an Internet Web site. The Web page contains graphics, text, and input fields. A map of the county is depicted as a graphic that can be clicked on with the mouse to perform basic map viewing functions. A child's cumulative risk of exposure to environmental lead can be determined from a residential address.

Elements of a Lead Exposure Risk Model (Lead Sources)

Lead-Based Paint

Lead-based paints are considered the most significant and widespread source of childhood lead exposure. The influence of lead-based paint is most often related to an individual's place of residence. Other places, such as relatives' homes, daycare centers, and schools, can also serve as a source of exposure for children.

The lead content of residential paints can be generally related to their period of production, and it is estimated that approximately three-fourths of the housing built before 1980 contains some lead-based paint. The lead content of paint was largely unregulated before the enactment of voluntary restrictions by the paint industry in the mid-1950s. Prior to these restrictions, paints routinely contained up to 50% lead by dry weight. In response to increased regulatory pressures, the lead content of paints was gradually reduced. By 1978, lead had been eliminated from paints produced for residential application. For the purposes of the lead risk model, it is assumed that a correlation exists between the year of a building's construction and the presence and concentration of lead in the paints.

For the purposes of tax collection, the county assessor's office collects parcel information that includes the property's address, value, ownership, and building data. Information regarding a home's year of construction can, therefore, be determined from the child's home address.

Lead-Contaminated Soils

Lead-contaminated soils are also important sources of lead exposure, primarily in older, urban residential areas. Their overall influence on lead exposure, however, is considered to be less than the influence of lead-based paint. To reflect this lesser influence, a weighting factor is applied to this risk feature.

Soil can be contaminated by lead from various sources, including weathered lead-based paint and the historical deposition of lead fallout from combustion sources such as incinerators and automobiles fueled with leaded gasoline. Because lead does not decay in the environment, deposits of lead from these sources accumulate over time in the upper 5 cm of undisturbed soils. Urban residential soils are generally more lead-contaminated than rural soils (18). This is because urban areas tend to have a greater concentration and longer operational history of emission sources, as well as higher traffic density and a larger stock of older housing.

The distribution of lead-contaminated soils can be approximated for urban residential areas based on the extent of urban development at a time when the inputs from the various sources are expected to have been the greatest. For the purposes of the model, urban areas developed prior to 1970 are assumed to be associated with greater soil lead contamination than rural or urban areas developed after that time. The cutoff date of 1970 reflects the enactment of regulations that resulted in reduced inputs from lead-based paints and atmospheric fallout from automobile exhaust and industrial sources.

Industrial Point Sources

Soils contaminated by airborne lead emissions from industrial sources can be characterized as a release point with a subsequent downwind zone of influence representing an atmospheric fallout area. A release point would be used to represent known industrial emission sources, such as secondary lead smelters, sewage sludge incinerators, and coal-fired power plants.

The extent of the plume and the degree of overall risk assumed to be associated with a source would be based on the type of the emitting facility, the nature and quantities of its emissions, the prevailing winds, and the facility's history of operation. The areal extent and the level of risk associated with these facilities are approximated, due to the lack of detailed environmental studies of air and soil contamination adjacent to these industrial emission sources.

Industrial and Solid Waste Disposal Sites

Industrial and other solid waste disposal sites can serve as significant sources of childhood lead exposure. Among Superfund sites, lead is the most frequently identified hazardous substance found in completed exposure pathways. The notable presence of lead at disposal sites is due to its persistence in the environment and its wide use and dissemination in industrialized countries.

Dakota County has created a countywide inventory of known solid and hazardous waste dumpsites. The inventory contains approximately 1,600 sites, ranging from farm dumps to extensive industrial/hazardous waste dumps. It includes sites associated with the operation of the large secondary lead smelter in the county, as well as smelter-related industries. Dumpsites and their surrounding areas are depicted as polygons. Dump attributes include waste characteristics, waste volume, and the potential for direct contact with waste or waste-impacted soils or water. Dumpsites possessing an increased potential for dispersal are assigned a buffer.

Blood Lead Level and Case Mapping

All current and available historic data regarding children's blood lead levels have been geocoded and included in the model. The Minnesota Department of Health provided blood lead testing data for all children in Dakota County screened between 1994 and 1997. These data are used in conjunction with birth record data to allow for the calculation of a blood lead screening "rate" for the at-risk population residing near the target residence. This information is provided to assist physicians in identifying areas where lead-poisoned children are concentrated and where screening efforts are inadequate.

Data Characteristics

Lead risk features are modeled as points and polygons. Points are used to represent the locations of known cases of elevated blood lead levels. The points are used to provide a summary of reported test results within a defined distance from the target location. (To protect confidential patient information, the points themselves are not shown.) Exposure risk features such as lead dumps, residual soil lead, industrial sources, and poverty are depicted as polygons. Parcels are also represented as polygons; the year in which they were built is retrieved to determine degree of risk.

Polygons are also used to represent regions of influence around a feature, either by buffering the feature itself or by representing the boundaries of a risk area such as a neighborhood or park service area. Each feature is modeled independently, to account for unique exposure risks associated with the lead source. Datasets are represented with a unique hatching pattern in which color gradation is used to represent degrees of risk. This method allows overlapping polygons to be visually distinguished and ranked.

Field verification of risk features is very important, because many features may not have been evaluated directly for actual lead exposure characteristics. These unverified exposure-risk features can still be incorporated into the model; efforts must be made, however, to better define their risk attributes or characteristics, as resources permit.

Determining Lead Risk Using the GIS Model

The application was developed to allow easy access, via the Internet, to detailed information regarding a child's risk of lead exposure. A query is initiated by entering a standard street address in the box next to the appropriate prompt. A certain amount of flexibility is allowed for matching misspelled street names. Because the matching process, or geocoding, uses a street centerline containing segments with assigned address ranges, the address does not need to match an actual property address. This technique establishes a geographic location for any address number that falls within the address range of a given street segment.

The Web page also includes several yes/no questions that were derived from a sample questionnaire developed by the CDC. These questions appear as a series of statements, accompanied by checkboxes. The user answers the questions by checking the corresponding box for each statement that applies. The questions are included to account for potential sources of lead exposure that are not included in the model, such as a recent move, occupational exposure, or home renovation plans. An affirmative answer to the questions automatically returns a recommendation to screen.

Pressing the button labeled "Search" initiates a search for the location of the address entered by the user. If a location is found, the program captures all risk datasets using pre-established techniques for spatially related features. A screening recommendation is calculated by adding the risk factors of these risk features. For example, the risk values shown in Table 1 are associated with the year of construction of a residence. As displayed in Table 1, residing in a home constructed before 1951 is cause for a recommendation to screen. The model also retrieves the average building construction date for all parcels within a 200-foot radius of the target location and returns the count of the structures constructed before 1941. This value is not directly incorporated into the risk calculation, but may be useful in identifying exposure risks from improper paint removal—for example, in cases in which the target residence is a newer home that is surrounded by older homes.

Table 1 Dakota County Screening Recommendations Associated with Year of Home Construction

Year of Construction	Degree of Risk	Screening Recommendation
1950 or earlier	High	Recommended screening
1951–1978	Medium	Screen when associated with other risk features[a]
1979–present	Low	Screen not indicated

[a] Including plans to renovate or location in an area of residual soil lead

Other polygon features including lead dumps, residual soil lead, and industrial lead sources within 400 feet of the target location are identified and incorporated into the overall screen recommendation. These features are assigned a corresponding risk factor, which is applied directly to the total risk as shown in Table 2.

Table 2 Dakota County Screening Recommendations Associated with Environmental Sources of Lead

Environmental Source of Lead	Degree of Risk	Screening Recommendation
Industrial source, lead dump, etc.	High	Recommended Screening
Residual soil lead	Medium	Screen when associated with other risk features[a]

[a] Including residence in home constructed between 1951 and 1978

Residing within the assigned zone of influence of a lead source returns a recommendation to screen. Exposure to multiple medium-risk sources creates an additive risk of exposure, which also can result in a recommendation to screen. When the application completes the analysis, a dot is displayed on the map at the target location and the screening recommendation is displayed. The map extents are changed to be centered on the location at the same scale. The “Zoom to Location” button is provided to change the map extents to include a 200-foot radius around the selected location.

Basic Map Functions

A list of options is provided specifying the operations performed when the mouse is clicked over the map graphic. These include basic functions for zooming and panning. An option is also provided for identifying locations by clicking the mouse over the map. This allows a total risk value to be determined for specific locations, such as street intersections, or for a general area if an exact address is unknown.

An index map is provided to help determine where the current view lies in relation to the entire county. Municipal boundaries are displayed in a small index map that is highlighted with the outline of the approximate extent of the current map view.

Client/Server Application

All map, search, and analysis operations are performed on a centralized Web server using a custom application, which responds directly to the user’s requests. This client/server application offers many benefits with respect to data and software upgrades and application enhancements. In addition, the Web server application returns a consistent representation of the model to all users on most computer platforms. The use of Web technology also provides access to many different kinds of information through the same interface. Background research, documentation, and other supporting information can be included or referenced directly through links to other Web sites on the Internet.

Software

The software used in this application consists of a Web server, a custom executable, and a client browser. The executable was developed using Microsoft Visual Basic and runs on Microsoft NT Workstation. MapObjects (ESRI, Redlands, CA) is a set of mapping software components; Visual Basic was used to incorporate basic mapping and querying capabilities from MapObjects into the application. MapObjects Internet Map Server, another set of software components from ESRI, was used to provide communications with the Web server and for image file format conversion.

Any Web browser supporting HTML 2.0 or greater should be compatible with this application. The use of standard HTML maximizes the number of compatible variations of computers, operating systems, and browsers that may be available to users for accessing this application. Minimal configurations, including low-end PCs and Windows 3.1, are assumed to be compatible.

Summary

A Web-based lead exposure risk analysis application provides many benefits by modeling real-world contributors to lead exposure and making this information readily accessible. Physicians and public health professionals will no longer have to rely solely on an individual's self-reported assessment of environmental lead exposure risks. They can now use objective information to target screening efforts on those individuals who are at greatest risk of exposure.

As additional blood lead results become available, and risk feature attributes are better defined, widespread use of the model will serve as an effective tool in the early identification of lead-poisoned individuals, while improving the cost-effectiveness of lead screening efforts.

The application is easy to use. Users can retrieve the lead exposure risk for an individual simply by typing in an address. In this fashion, localized areas possessing high exposure characteristics can be readily identified. The model accesses parcel-specific data; thus, pockets of elevated risk can be discerned within large geographical units such as census tracts or zip code areas.

Supplying this application on the Internet provides health professionals with near-universal, on-demand access to detailed data that would otherwise not be available. The application makes available previously obtained blood lead results for others in the vicinity of the target residence, thus providing health professionals with feedback regarding the prevalence of screening activity as well as the number of incidences of elevated blood lead in the provider's service area.

Use of Web server technology allows the data elements of the application to be maintained regularly and frequently without burdening the users with file maintenance. The data can also be analyzed and presented to end-users in a consistent manner irrespective of computer resources. Access can be given to data derived from sensitive patient information without compromising privacy. Research, supporting documentation, and links to related Web sites can also be assembled and easily provided.

Screening and early detection of lead exposure are effective means of preventing cases of severe lead poisoning; however, many children exposed to toxic levels of lead are not being identified. The use of GIS and Internet technology can assist in the identification of children at greatest risk of lead exposure and help ensure that exposed children receive the necessary services.

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